NATIONAL BUREAU OF STANDARDS REPORT

7339

EFFECT OF FIBER COMPOSITION ON TEXTILE FLAMMABILITY
REPORT OF PRELIMINARY WORK

By

Marjorie W. Sandholzer

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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ABSTRACT

A group of ten fabrics, similar in construction and weight but each knit from a different textile fiber, were subjected to three established textile flame tests and to a test designed to measure the heat transferred from a burning fabric to an adjacent surface. Because of the pronounced difference in response to heat and in burning behavior between the fabrics of natural fibers and those of synthetic fibers, valid comparisons between fabrics of the two types were difficult. The fabrics of natural fibers in the group were placed in the order of wool, cotton, and viscose rayon on the basis of increasing burning rate, as indicated by the three methods used. Two synthetic fabrics, Dynel and Dacron, did not support combustion in any of the tests; the others showed burning rates in a range comparable to that for the fabrics of natural fibers. The heat transferred to an adjacent surface varied with the fiber and construction of the material and, as registered by the method employed, appeared to range from approximately 20-50 percent of the heat produced by the burning fabric.

1. INTRODUCTION

The ease of ignition and the burning rate of a fabric are greatly influenced by the physical characteristics of the material, such as the weight, type of weave, and surface texture. Because normally available fabrics differ widely in these physical characteristics, it has been difficult to arrive at more than a very general assessment of the effect of fiber composition on the burning behavior of a material. In order to substantially reduce the physical variables, a group of ten fabrics, as similar as feasible in weight and construction but each knit from spun staple stock of a different fiber composition, was obtained on special order from the North Carolina State College. It is believed that such a group of fabrics should prove helpful in studying the fire hazards connected with various textile applications.

2. Flammability Tests and Results

The first work with the group of fabrics has consisted in determining their behavior in several standard textile flame tests. Two of the tests used are described in Federal Specification CCC-T-191b as Method 5902 and Method 5906. The third is described in the N.F.P.A. Tentative Standard for Classification of the Flammability of Wearing Apparel, No. 702-T. The three methods have several similarities. They require test specimens of similar size (11-12 inches long and 2-3 inches wide), and for each, the specimen is placed in a metal holder which clamps each long edge of the strip leaving a center width of 1-1/2 or 2 inches exposed to flame progress. All use a flame applied to an edge of the fabric as an ignition source, although the igniting flame varies in size. The methods differ primarily in the position in which the specimen is tested and, in consequence, in the means adopted for gauging flame progress.

Method 5902 was designed to indicate the comparative flame resistance of nonflammable or difficultly flammable textiles and is not readily adaptable to a comparison of easily flammable materials. The specimen is supported in a vertical position, a defined flame exposure is applied to the lower end, and the resulting length of fabric char and duration of fabric flaming are used as criteria of performance. With a readily flammable material the flame front is so poorly defined that visual determination of the burning rate is not feasible, although, for fabrics which burn in a similar manner, a rough comparison may be based on the time required for the entire specimen to burn and all flaming to cease.

In Method 5906 the fabric specimen is supported in a horizontal position, ignited at one end and, after burning of the fabric has become established, the time required for the flame front to progress a 10-inch distance is recorded manually with a stopwatch. The method provides little differentiation among difficultly flammable fabrics, but permits calculation of a burning rate for readily flammable materials.

The N.F.P.A. Tentative Standard uses a specimen position inclined 15 degrees from the vertical. The specimen is ignited at the lower edge by a defined flame, and the time interval between application of the igniting flame and the burning of a taut cross-thread 10-inches from the lower end of the specimen, is automatically registered on a stopwatch. This method also permits calculation of a burning rate, although the flame progress is defined by factors which differ from those of the horizontal method.

In all of the tests the basic difference in burning behavior between the natural fibers and most of the synthetic fibers was obvious. In general the natural fibers are not thermoplastic, and the specimens burned or charred completely while remaining in position. The wool intumesced and showed a somewhat plastic condition but commonly produced a brittle, foamed char which remained in place. Most of the synthetic fibers, on the other hand, are highly thermoplastic and soften ahead of the flame. The fabric structure flowed into melted, flaming globules which either dropped away or collected along the clamped edge of the specimen, and flame progress was irregular and difficult to gauge. Smoke evolution was notably much heavier from all of the synthetic fabrics than from those of natural fibers.

The results obtained with the ten fabrics in the three test methods are summarized in Table 1. Considered individually, each method showed decided variations in flammability and rate of burning among the different materials. In addition, although the criteria of flame progress differ among the methods, the data suggest some general effects of specimen position on burning behavior and burning rate. In the vertical test, five of the fabrics burned the full specimen length of 11 inches, and of these, the wool, cotton, and viscose rayon burned in a reasonably similar and consistent manner. For these three the duration of afterflaming (flaming of the fabric after withdrawal of the igniting flame) can provide a rough comparison of burning rate, and would place them in the same relative order as the other two methods. For the two synthetic fabrics, Acrilan and Orlon, which were completely destroyed in the vertical test, the duration of afterflaming had little significance since it represented primarily the haphazard flaming of globules clinging to the clamped sides of the specimen. With the other five synthetic fabrics the length burned indicated essentially the distance directly affected by the igniting flame, which generally appeared as an open, flame-shaped area from which the fabric had melted and drawn away; the afterflaming consisted of continuted flaming along the edges of this area, usually without further fabric destruction.

Table 1. Results of Flammability Tests.

Fabric Description			Vertical Test (avg. of 3 specimens)		15° Angle Test (avg. of 5 specimens)	Horizontal Test (avg. of 3 specimens)
Name	Fiber Type	Weight	Afterflame Duration	Length Burned	Burning Rate	Burning Rate
		oz/yd²	sec	in.	in/min	in/min
Wool	Wool	9.1	54	11.0	18.4	
Cotton	Cellulose	9.6	30	11.0	25.2	3.6
Rayon	Regenerated Cellulose	9.7	23	11.0	31.4	4.4
Acetate	Cellulose Acetate	9.7	37	5.8	18.1	4.1
Arnel	Cellulose Triacetate	9.1	22	4.2	24.4 (1)	8.1
Nylon	Polyamide	9.7	9	3.8	9.2 (2)	4.5
Acrilan	Acrylic	9.5	43	11.0	19.5	3.1
Orlon	Acrylic	10.1	54	11.0	25.1	4.3
Dynel	Modacrylic	9.3	0	5.2		
Dacron	Polyester	9.3	0	4.5		

(1) Average of 4 specimens; one specimen failed to burn 10 inches.

(2) Average of 2 specimens on which flame progress was very erratic; 3 specimens failed to burn 10 inches.

As would be expected, the burning rate appeared to increase as the specimen position approached the vertical, and to become most rapid in that position, as long as the flame could maintain contact with the fuel. The vertical position, however, favored the melting and withdrawal from the flame to which the synthetic fabrics were prone, and several which burned in the horizontal position failed to burn in the vertical position. When the specimen position was inclined slightly from the vertical they burned more rapidly than in the horizontal position, although on some individual specimens of two of the fabrics the flaming portions still dripped away to the extent that flame spread was stopped before the specimen was consumed.

With regard to the burning rates of the various fabrics relative to each other, the natural fibers were placed in the order of wool, cotton, and viscose rayon, on the basis of increasing rate, by each of the three test methods. For the synthetic fabrics, only general conclusions appear justified, inasmuch as their burning was commonly uneven and the differences noted in rate might well have resulted primarily from differences in melting temperature and consequent dripping tendency. It is significant, however, that the Dacron and Dynel failed to support combustion in any of the test methods used, and the other synthetic fabrics appeared to burn at rates in approximately the same range as those for the fabrics of natural fibers.

3. Heat Transfer Test

In addition to burning characteristics and rate of burning, the amount of heat evolved and supplied to an adjacent surface from a burning fabric is also of interest in studies of the hazard presented by various textile applications. Following the design of a British method for measuring such heat transfer, an apparatus was assembled and used in testing a number of fabrics, including the group of similarly constructed knit materials.

For the tests, a specimen 30 inches long and 4 inches wide was suspended vertically 1/2 inch from an asbestos millboard back panel. In order to prevent severe rolling of the edges of the knit fabrics, however, those specimens were cut 4 1/2 inches wide and a narrow frame (about 5/16 inch wide) of heavy paper was stapled to the outside edges of the specimen. The amount of paper introduced was so small and well removed from the center of the specimen that it could not materially affect the heat produced by the burning fabric at the points of measurement. In test position the specimen was held at the top by a spring clamp and, to prevent fluttering or curling during burning, it was laced under and over six appropriately spaced cross wires, held at a 1/2 inch distance from the back panel by two metal spacing strips running lengthwise of the panel. These spacing strips were set 6 inches apart, and the suspended specimen was centered between them. The specimen was ignited across the full width of the lower end and allowed to burn freely. To provide a measurment of the heat supplied to the asbestos board backing at various heights, four cylindrical copper plugs of 1/2 inch diameter were set into the back panel, flush with the panel surface and spaced 4 inches apart, the uppermost being 5 1/2 inches below the top edge of the specimen. The plugs were surface coated with India ink to improve heat absorption, and a thermocouple attached to the back of each plug permitted a continuous recording of the temperature of the plug. From the recorded temperature rise (disregarding the various small heat losses from the plug and wires) and the characteristics of the plug, the heat dosage was calculated from the relation:

$$Q = c\rho t\theta \text{ cal cm}^{-2}$$

where c = specific heat of the plug in cal $\text{gm}^{-1}\ {}^{\circ}\text{C}^{-1}$
ρ = density of the plug in gm cm^{-3}
t = thickness of the plug in cm
θ = temperature rise in °C.

Use of a dual-channel recorder permitted measurement of the temperature rise of two of the plugs during the same test.

The results obtained on the five knit fabrics which supported combustion in the vertical position are presented in Table 2. Data for three woven fabrics tested under comparable conditions are also shown. The difference in heat dosage values obtained in the two plug positions used in the tests did not appear to be significant, and the results at only one plug position (5 1/2 inches below the upper end of the specimen) are included in the table.

Table 2. Heat Transfer Results

Name	Fabric Description		Weight	Heat Transfer		Avg. Heat Dosage	Potential Heat*	
	Fiber	Construction		No. of Tests	Avg. Temp Rise			
			mg/cm^2		°C	cal/cm^2	cal/gm	cal/cm^2
Wool	Wool	Knit	31.0	3	54.3	31.8	2670	83
Cotton	Cellulose	Knit	32.4	7	101.0	59.1	3957	128
Rayon	Regenerated Cellulose	Knit	32.9	10	105.1	61.5	3695	122
Sateen	Cellulose	Twill weave	29.2	5	64.9	38.0	3988	116
Bengaline (Cotton and Rayon)	Cellulose and Regenerated Cell.	Ribbed weave	22.0	5	64.2	37.6	3822	84
Muslin	Cellulose	Plain weave	6.8	5	14.0	8.2	4519	31
Acrilan	Acrylic	Knit	32.1	5	63.0	36.9	5120	164
Orlon	Acrylic	Knit	34.4	5	45.6	26.7	4463	154

*Determined by a modified method

Presented also in Table 2 are modified "potential heat" values which provide an approximate measurement of the actual amount of heat released by the various fabric strips in burning. The values were obtained by a differential bomb calorimetric method* and were calculated as the difference between the heat of combustion of the original fabric and that of the residue remaining after the fabric was allowed to burn freely in air. For the cellulosic fabrics, no significant residue remained after burning in air, but for the wool and synthetic materials, air burning left charred residues amounting to 30-40 percent of the weight of the original sample. By taking into account the fabric weights, values for the heat produced by the burning strips may be calculated, permitting a rough indication of the proportions of that heat which were registered by the copper plug indicators. The values given in Table 2 are, for the most part, based upon one determination.

From observations during the tests it was evident that the manner in which the fabric burned had a considerable effect on the temperature rise obtained. If the charred or nearly ashed fabric structure remained hanging in place after flaming had ceased, the temperature continued to rise for some time, usually until the char fell away terminating radiant heating of the plug. In general the cotton and rayon fabrics exhibited this type of behavior, although there were noticeable differences among them in the tenacity of the char. The char of the woven fabrics tended to fall away more quickly than that of the knit fabrics, and the knit rayon remained in position until the ash had become almost a powder. With the restriction in air flow introduced by the backing panel, the wool burned poorly and unevenly, and two of the five specimens tested burned only part way. On the two synthetic fabrics, Acrilan and Orlon, the flames spread violently and rapidly with the characteristic melting and dripping of the material, which continued to burn in a mass at the base of the panel. For the most part, the plugs were subjected to a vigorous but relatively transient burst of flame, though at times parts of the molten, flaming material caught on the lacing wires or stuck to the asbestos panel near a plug and provided some additional exposure.

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* The method described in ASTM preprint "Potential Heat" by Loftus, Gross, and Robertson, was used except that free burning in air was substituted for firing in a muffle furnace.

The numerical results as well as the test observations suggest that the heat dosage determined by this method is a function of fabric construction and burning behavior, in addition to fabric weight and perhaps fiber content. The wool values are questionable because of erratic burning and are therefore inconclusive. The group of cellulosic fabrics showed the most uniform burning and provided probably the most reliable results among the materials tested. With the exception of the muslin, the cellulosic fabrics gave similar potential heat values, with an indication of slightly lower values for rayon than for cotton. The higher potential heat obtained for the muslin may have been due to the considerable dressing which the material carried and which the other fabrics did not have. The heat dosage values for the cellulosic materials, however, showed pronounced differences which appeared to bear a considerable relation to the type of construction. Thus, the two knit cellulosic fabrics gave closely similar heat dosage values, which amounted to approximately half the heat exposure calculated on the basis of fabric weight. The sateen and bengaline, both woven fabrics but quite different in type of weave, also gave almost identical heat dosage values. The value for the bengaline was again nearly half the calculated heat exposure, but that for the sateen was not more than one third the calculated exposure. The very light weight of the muslin was, of course, reflected in a very low heat dosage value, which, however, was only about one fourth of the calculated heat exposure. The heat dosages determined for the two knit acrylic fabrics were decidedly lower than those for the knit cellulosic materials and represented relatively small proportions of the calculated heat exposures, an effect which appeared consistent with the type of burning observed.

4. Summary

Due to a basic difference in their response to heat, the fabrics of natural fibers and those of synthetic fibers showed a pronounced difference in burning behavior. In general the natural fibers are not thermoplastic and the fabric structure remained in position during burning, while most of the synthetic fibers are highly thermoplastic and the fabric structure quickly melted into viscous flaming masses which dripped away from the test position. This basic difference in burning behavior makes it difficult to arrive at valid comparisons between fabrics of the two types as to burning rate, heat production, and other characteristics by which the relative hazards may be gauged.

The fabrics of natural fibers which were studied may be listed in the order of wool, cotton, and viscose rayon, on the basis of increasing burning rate as indicated by the three test methods employed. In the measurement of heat transferred from a burning fabric to an adjacent surface, the determinations on wool were not sufficiently reliable to justify a comparison with the other fibers. The cotton and rayon knit fabrics supplied heat to an adjacent surface in essentially the same amount, which appeared to be approximately one-half the heat produced by their burning. A woven cotton sateen of comparable weight, however, supplied to the adjacent surface only about 60% as much heat as the knit cellulosic fabrics, or about one-third of the heat produced by its burning.

Among the synthetic fabrics studied, the Dynel and Dacron did not support combustion in any of the tests applied. The two acrylic fabrics, Acrilan and Orlon, burned readily in either the horizontal or vertical position, but the other three synthetic fabrics (cellulose acetate, Arnel, and nylon) failed to burn in the vertical position because of melting and drawing away from the flame. The burning rates of the synthetic fabrics, as determined in the horizontal and 15° angle positions, were in a range which appeared reasonably comparable to that for the fabrics of natural fibers. The two acrylic fabrics (the only ones of the synthetic group which burned in the required vertical test position) supplied about 50-60% as much heat to an adjacent surface as the knit cellulosic fabrics, amounts which appeared to be around 20% of the heat produced by their burning.

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